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APPLICABILITY OF ERTS-1 TO MONTANA GEOLOGY

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16. Abstract

A detailed Band 7 ERTS lineament map covering western Montana and northern Idaho has been prepared and is being evaluated by direct comparison with geologic maps, by statistical plots of lineaments and known faults, and by field checking. Lineament patterns apparent in the Idaho and Boulder batholiths do not correspond to any known geologic structures. A Band 5 mosaic of Montana and adjacent areas has been laid and a lineament annotation prepared for comparison with the Band 7 map. All work to date indicates that ERTS imagery is very useful for revealing patterns of high-angle faults, though much less useful for mapping rock units and patterns of low-angle faults.

Large-scale mosaics of U-2 photographs of 3 test sites have been prepared for annotation and comparison with ERTS maps. Mapping of Quaternary deposits in the Glacial Lake Missoula basin using U-2 color infrared transparencies has been successful resulting in the discovery of some deposits not previously mapped. Detailed work has been done for Test Site 354 D using ERTS imagery; criteria for recognition of several rock types have been found. Photogeologic mapping for an ERTS scene in southeastern Montana suggests that Wasatch deposits occur where none are shown on the state geologic map.

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PREFACE

The primary objective of the investigation is to develop tectonic and photogeologic mapping methods using ERTS imagery for both forested and sparsely vegetated terrain. This involved preparation of a Band 5 ERTS mosaic for the entire state as well as U-2 metric camera mosaics for three test sites. Major effort went into construction of a large-scale lineament map for western Montana and development of methods to evaluate it. Photogeologic studies emphasized mapping various rock types in Test Site 354 D, Quaternary deposits in the western test sites, and Mesozoic and Tertiary units in eastern Montana.

It is now clear that ERTS imagery is straightforwardly useable, even in forested regions, for producing lineament maps having a lineament pattern subjectively and statistically comparable with the pattern of faults shown on conventional geologic maps. The lineament maps appear to be geologically significant. Efforts to use ERTS imagery for photogeologic mapping of rock units have met with limited success to date but are continuing and it seems likely that locally applicable criteria for recognition of rock units will eventually emerge.

We recommend partial photographic recoverage of Test Sites 354 A&C, B and D in the fall to overcome limitations in the original coverage.

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ILLUSTRATIONS

INTRODUCTION

This report covers continuing work involving tectonic and photogeologic mapping methods utilizing ERTS imagery. During the period, an ERTS Band 5 mosaic was prepared for Montana and adjacent areas, and 1:125,000 scale U-2 photograph mosaics were laid for three of our four test sites. Major effort went into scene-by-scene annotation and compilation of a detailed ERTS lineament map for the western Montana area at a scale of 1:500,000. The northwestern part of this map was compared to map truth on a line-by-line basis and by the statistical method of constructing rose diagrams representing lineaments and mapped faults for two domains. Photogeologic studies were carried out mainly for areas in Test Sites 354 A-C, D, and F. In March, Dr. Weidman attended the Symposium on Significant Results Obtained from ERTS-1 and presented a paper which is listed under References.

MAIN TEXT

Data Utilization Techniques

To overcome the difficulty of making tone-matched, large-scale enlargements from dense late spring and summer NDPF 70mm negatives we have worked out the following procedure in cooperation with the Forest Service Division of Engineering Photoreproduction Section. Groups of 70mm positives of comparable average density were exposed in a LogEtronics printer yielding contact internegatives on large sheets of Kodak 4127 Commercial Film (Estar thick base). A set of negatives for bands 5 and 7 was prepared in this manner for statewide mosaics representing orbital dates as disparate as 7 August and 16 October, 1972. The resulting negatives were quite even in average tone and allow enlargement in a 75 watt enlarger using reasonable exposure times. Although an increase in graininess resulted from this process, enlargements at a scale of 1:500,000 are quite acceptable for interpretation purposes.

Negatives prepared as described above were utilized by the Forest Service in laying a partly controlled Band 5 mosaic for Montana and adjoining areas at an original scale of 1:850,000 (Figure 1). We had previously

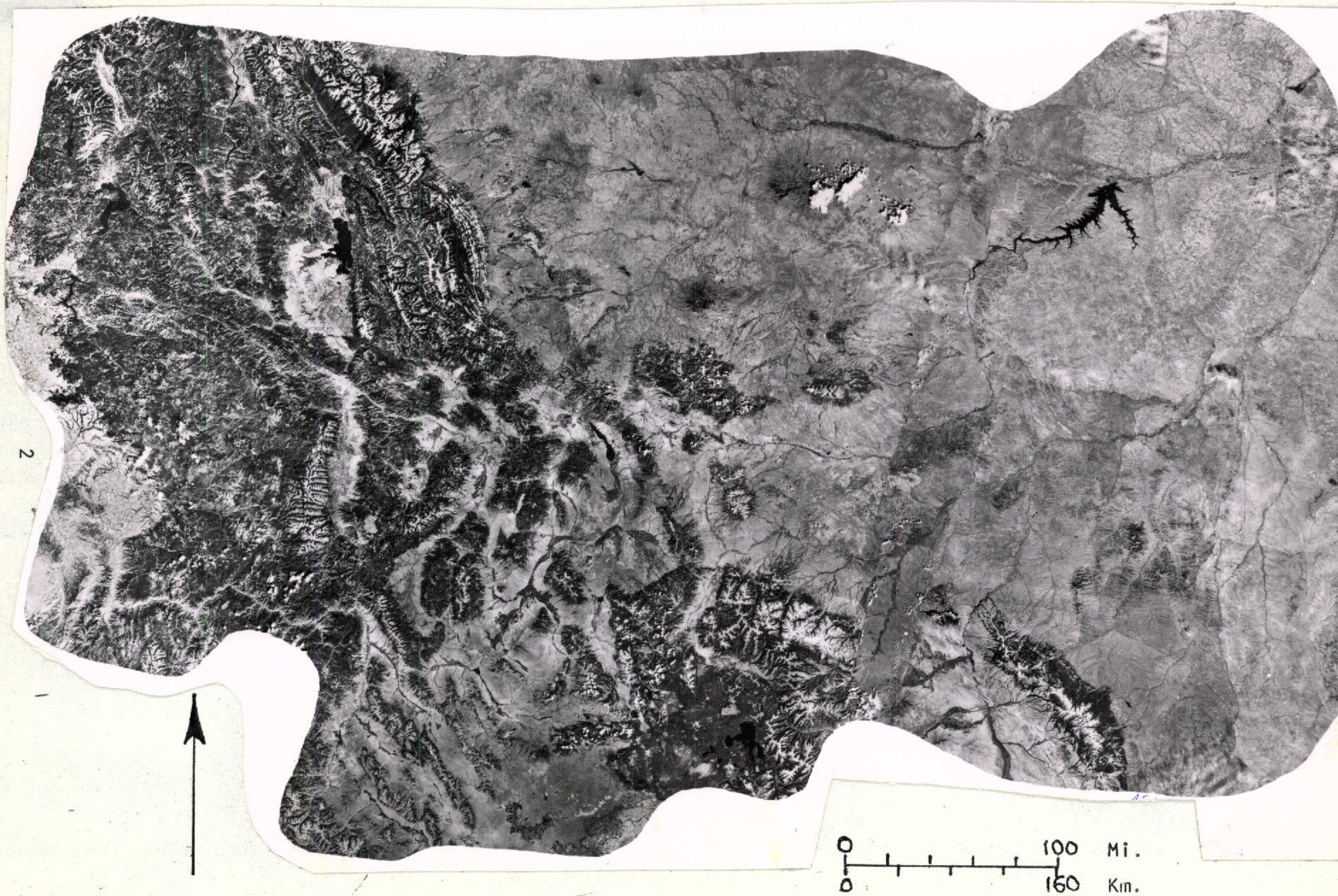

Figure 1. Partly controlled ERTS mosaic of Montana and adjacent areas for Band 5, imaged during late summer and fall, 1972. Original scale 1:850,000. Prepared by USDA, Forest Service, Division of Engineering Photoreproduction Section, Missoula, Montana.

attempted to lay a carefully controlled Band 7 mosaic covering western Montana at a scale of 1:500,000 utilizing the Geologic Map of Montana (1955) as a base. This was unsuccessful because distortions inherent in the base map projection prevented laying even a few uniformly enlarged prints without diverging significantly from map control. To lay the mosaic statewide without diverging from map control would have required custom enlarging each scene to precisely match local control by tilting the easel. Because such a project is not appropriate under our proposal, the enlargements were utilized individually for lineament annotation instead of in mosaic form.

A second generation ERTS lineament map of the western Montana area was prepared on a scale of 1:500,000 utilizing annotated acetate sheet overlays for individual scenes in Band 7. Annotations were first made on pictures imaged during the late summer; additional lines brought out by low sun angle enhancement on late fall imagery were added later from a second set of prints. The annotation procedure was to first draw the rivers and lakes in blue, then the fracture-controlled lineaments in a second color, and finally stratigraphically-controlled lines in a third color. Each scene was annotated by several operators using assigned colors, then the different overlays were registered, punched, and assembled with plastic map studs for preparation of the edited master overlay. These were traced onto a sepia drainage map drawn from the geologic map of Montana and adjacent Idaho. Sidelap provided a check on the objectivity of the map and the validity of through-going lineaments, which had been annotated separately in sections. The resulting lineament map (Figure 6) is probably more valid than one drawn over a mosaic on a single overlay sheet.

A detailed comparison of ERTS lineaments with geologic map truth was made for key areas. On blue-line prints of master overlays for given scenes, lineaments were numbered and then compared with geologic maps. A card was prepared for each numbered lineament, indicating whether or not it corresponds to a mapped fault, and if so, the name, nature, and length of the fault. Special notes were made for lineaments which appear to represent some other feature, such as dikes, joint sets or sedimentary beds.

A statistical approach to evaluating the validity of ERTS lineaments involved the preparation of rose diagrams (Figures 7 and 8) for two homogeneous structural domains. For each domain pairs of rose diagrams were constructed showing for each 5 degree azimuth direction the number and total length of lineaments (in one case) and of map truth faults (in the other case).

To facilitate understanding the relationships between ERTS annotations and test site geologic ground truth, we prepared U-2 mosaics at contact print scale of metric camera pictures for three of our four test sites (Figures 2, 3, and 4). These mosaics are being used as a base for plotting annotations interpreted under the zoom stereoscope from the original color infrared metric camera photography. The mosaics themselves were prepared from black and white contact prints made from panchromatic internegatives of the original color transparencies. The available resin-backed prints, which do not adhere well to gum arabic, were fastened with adhesive transfer tape spread by a commercial roller gun.

Experimental photogeologic annotations were made on overlays to Band 7 enlargements printed at a scale of 1:250,000 for test sites 354 D and F. Although the enlargements do not afford additional geologic information over that seen in 1:500,000 scale prints, they have the advantage of providing adequate space for detailed annotations.

Tectonic Analysis Feasibility Studies

Lineaments

From the first working copy of the statewise Band 5 mosaic (Figure 1), we have constructed a preliminary coarse lineament map (Figure 5), which will be refined and redrawn over a larger scale enlargement to provide a comparison of Band 5 lineaments with those of our detailed Band 7 lineament map (Figure 6).

Methods of constructing and analyzing the detailed lineament map of the western Montana (Figure 6) have been discussed under Data Utilization Techniques. In preparing annotations for this map, we have been strongly impressed with the advantage of using low sun angle illumination for enhancement of topographically expressed lineaments. Some major geologic features, such as the Island Park Caldera, are obvious in fall imagery but barely discernable in late August imagery. In general, late October and November

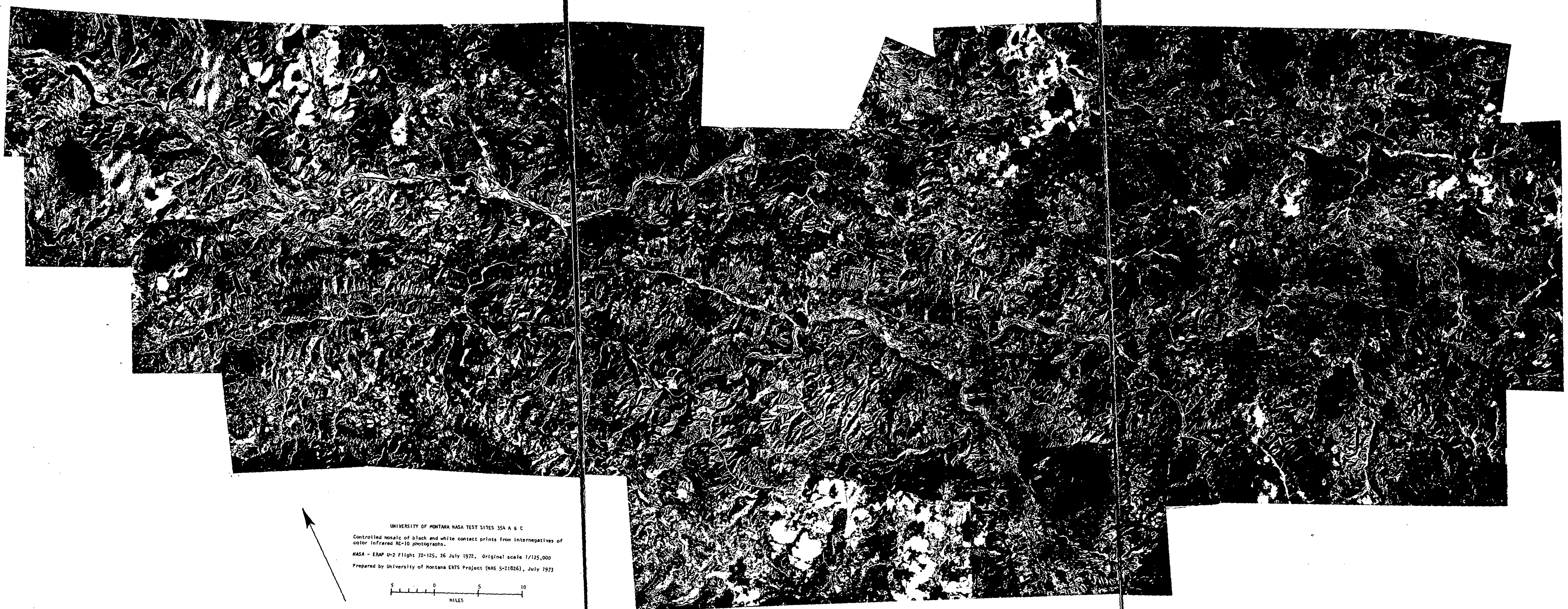

Figure 2. Aerial photomosaic of Test Site 354 A & C (Garrison Jct. on east; Noxon Reservoir on west; Missoula just east of center).

FOLDOUT FRAME 1

FOLDOUT FRAME 2

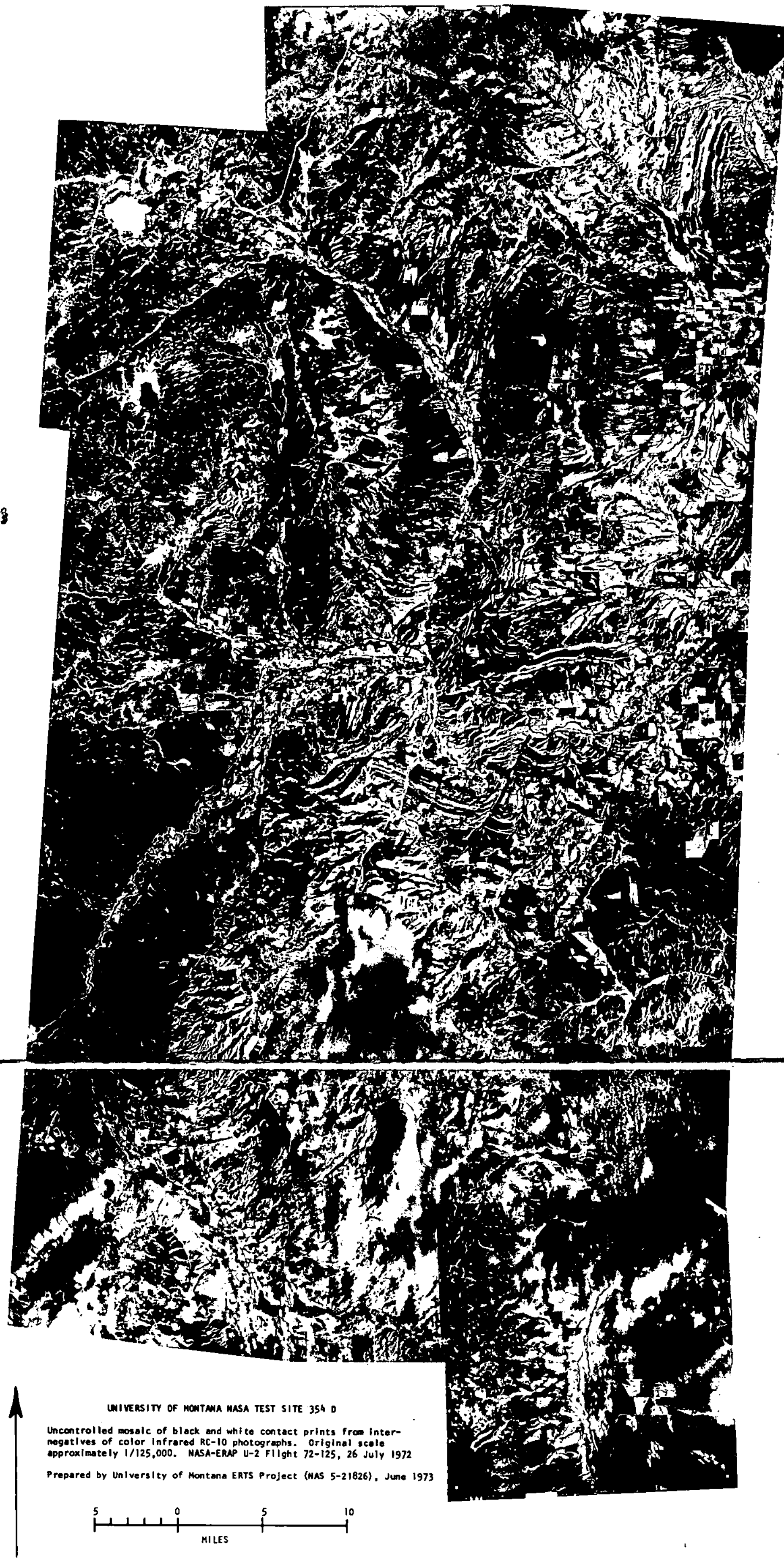

Figure 3. Aerial photomosaic of Test Site 354 D. (Jefferson Valley and Tobacco Root Mts. in south; Boulder River Valley and southern Elkhorn Mts. in north).

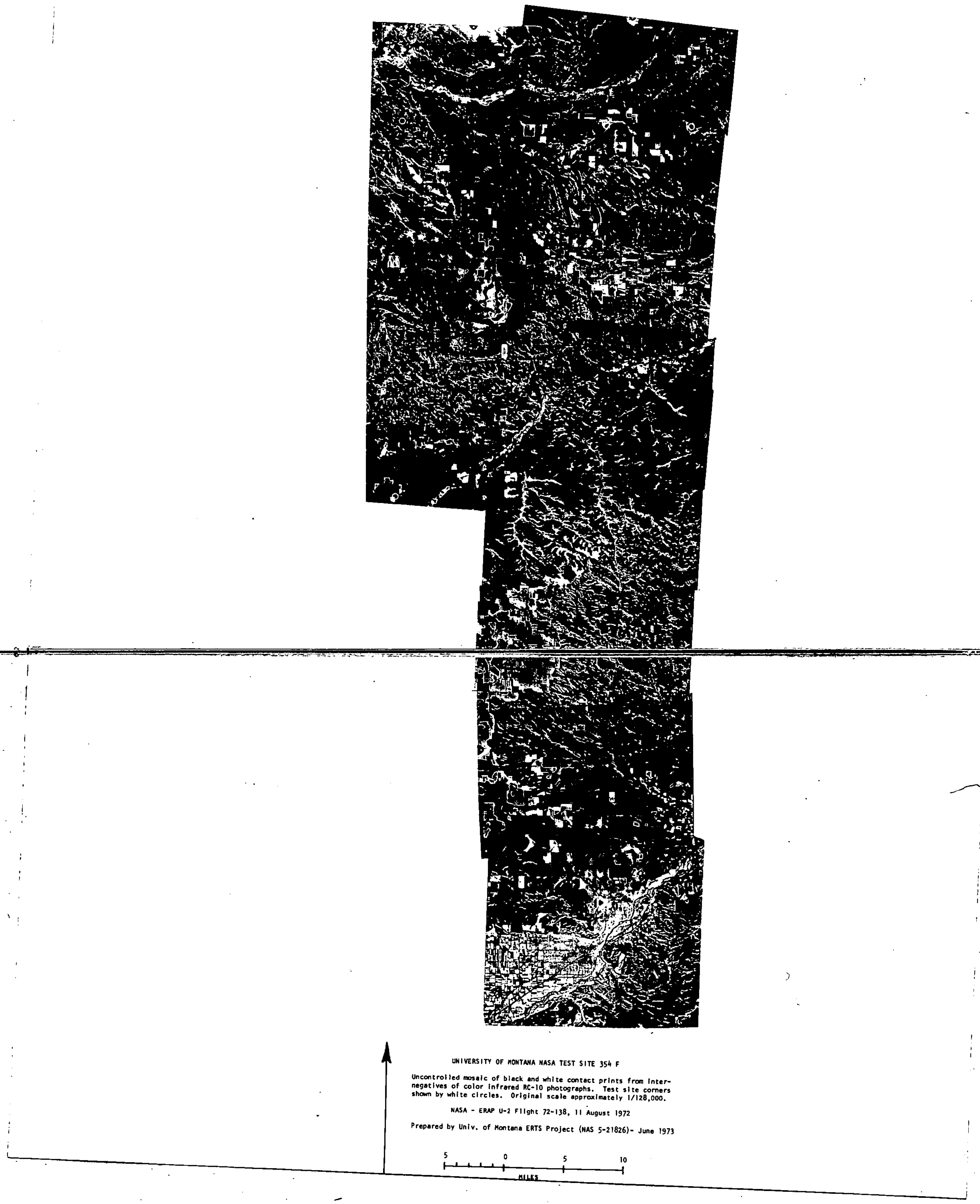

Figure 4. Aerial photomosaic of Test Site 354 F and adjoining Billings area to south. White circles mark corners of test site, which includes Roundup and Musselshell River.

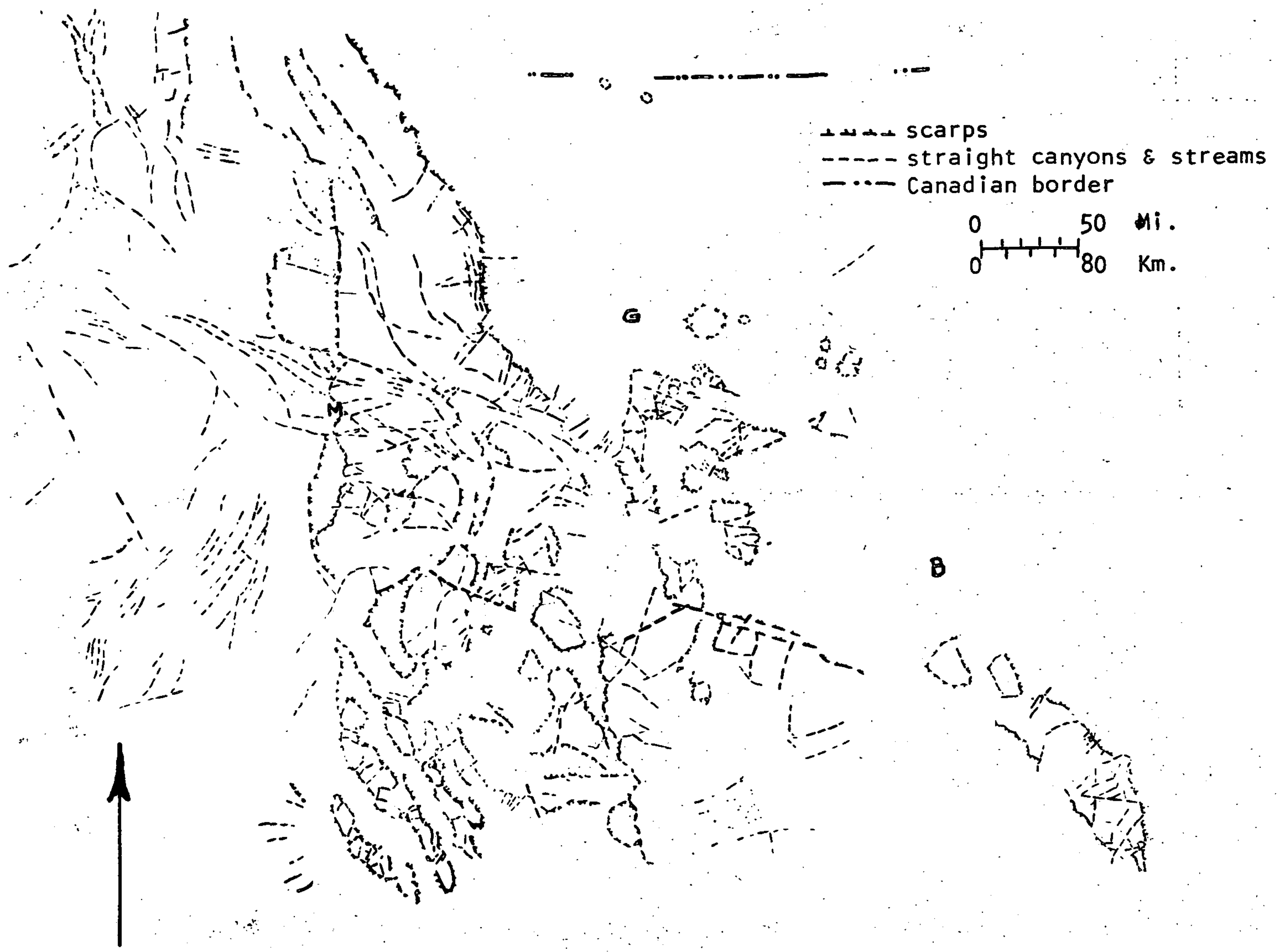

Figure 5. Preliminary coarse lineament map for Montana area drawn from ERTS red band mosaic (See Figure 1) at original scale of 1:850,000. B - Billings, G - Great Falls, M - Missoula.

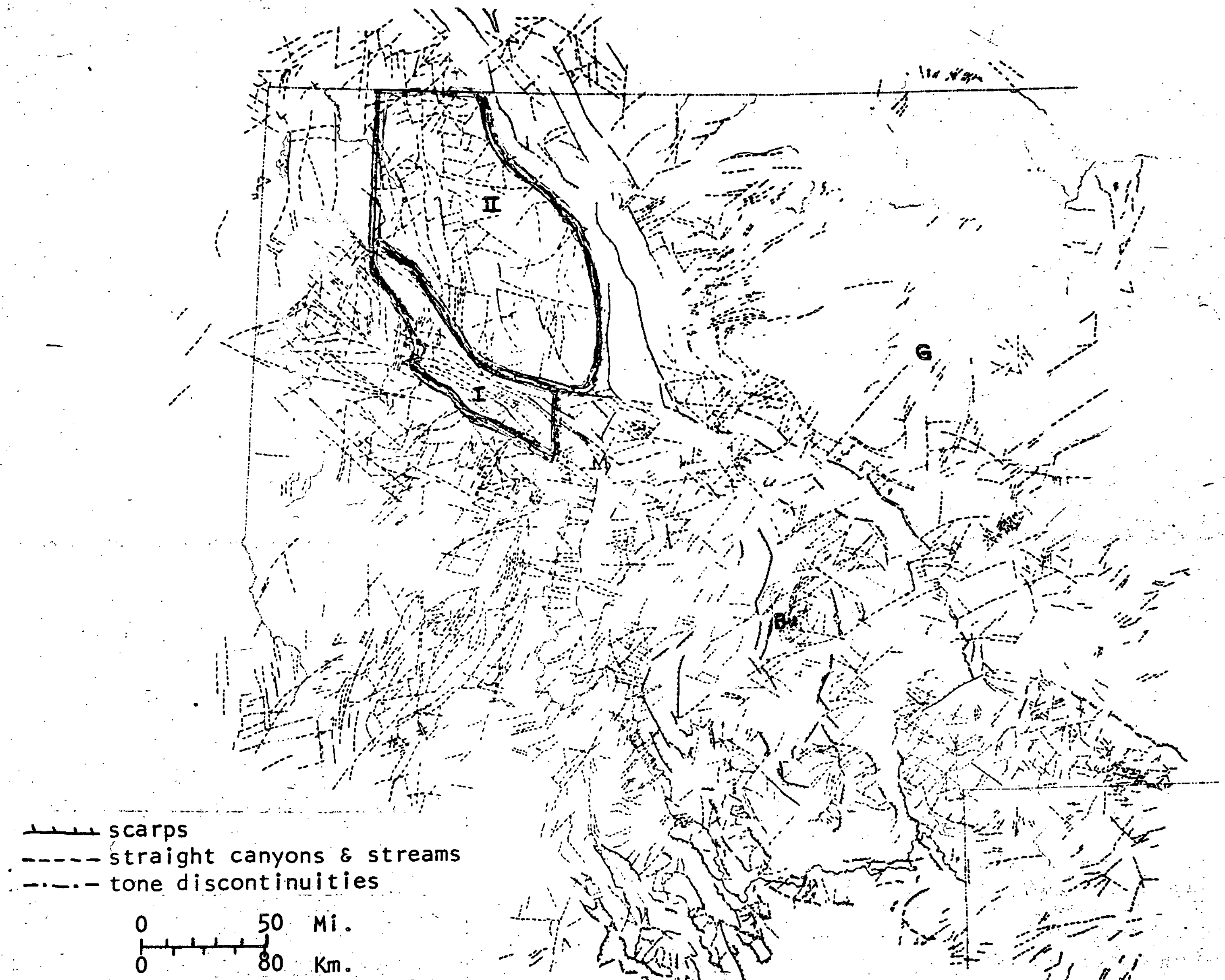

Figure 6. Detailed ERTS lineament map of western Montana area representing composite of 19 overlays each for both late summer and fall Band 7 images; original scale - 1:500,000. Bi - Billings, Bu - Butte, G - Great Falls, M - Missoula. Broad lines delineate structural domains for Figures 7 and 8.

images, with sun angles of 20 to 30 degrees are far superior for our purposes to late August images with sun angles of 47 ± degrees. Our detailed work confirms the observation previously reported that the morning illumination of ERTS imagery enhances lineaments of northeast trend and minimizes the opportunity to recognize lineaments of northwest trend. Previously known major geologic structures of northwest trend are consistently difficult to identify, whereas strong lineaments of northeast trend have been found where no major structure has previously been mapped. Evaluation of the extent of bias due to illumination direction is still incomplete, but will doubtless emerge as statistical consideration of the lineament map proceeds.

All who worked on the lineament map felt subjectively that the map is a reasonably accurate reflection of the broad geologic style for most of the structural provinces involved. Only locally did truly surprising lineament patterns emerge (discussed later).

Detailed evaluation of the lineament map has been undertaken for northwestern Montana and adjacent portions of northernmost Idaho (the general area of Domains I and II, Figure 6). Good quality geologic maps provide more ground truth data in this area than in most of the rest of the region involved in the present study. The area is also a part of the northern Rocky Mountains which seems to be least favorable for geologic interpretation of ERTS imagery because forest cover is heavy, soil mantle is generally thick, geologic exposure is at the minimum for the region, and bedrock consists almost entirely of sedimentary formations belonging to the Precambrian Belt Supergroup, all with very similar responses to the processes of weathering and erosion. The region provides a most demanding test of the utility of ERTS imagery for geologic investigations.

The first step in evaluation of the lineament map consisted of painstaking comparison with existing geologic maps to ascertain degree of correspondence with previously mapped ground truth. Approximately 40 percent of the lineaments were found to correspond with faults, fold axes, contacts or other known geologic features depicted on published maps. Approximately 32 percent were not directly shown in published geologic maps but could be added to them without doing violence to either the mapped outcrop pattern or the apparent style of structural deformation. The balance of the lineaments, approximately 28 percent, are inconsistent with known ground truth because they fall in places where significant faults could not be added to the map without doing violence to the outcrop pattern and in some cases materially altering the apparent style of deformation. These lineaments were not previously known and their significance is not yet established. They will be discussed with co-investigator Johns, who is most familiar with the geology of northwestern Montana, to ascertain which lineaments probably represent meaningful geologic lines and which, if any, are likely to have no geologic meaning. Following a field check of selected lineaments a detailed map will be prepared summarizing the status of all lineaments in the area.

The second step in evaluation of the lineament map involves statistical comparison of the lineament and geologic maps in the same portion of northwestern Montana selected for the direct comparison study described above. For this step, rose diagrams were prepared as described under Data Analysis Techniques.

Figure 7 represents a very strongly faulted terrane referred to as the Lewis and Clark lineaments domain. There the rose diagrams derived from measurements on the lineament map and the ground truth geologic maps resemble each other very closely. Both show a strong set of northwest-trending structures and very much weaker sets trending in other directions. Rose diagrams derived from the lineament and geologic maps in this domain are so similar that they are virtually interchangeable and the lineament map would appear to be a statistically valid substitute for the geologic map insofar as linear structures are concerned.

Figure 8 represents the northwestern Montana structural domain located in perhaps the least deformed portion of the region, where the rose diagrams derived from measurements on the lineament and geologic maps differ significantly for reasons that are not yet clear. The lineament map contains a strong set of nearly north-trending structures that are not well represented on the geologic maps. Several other less striking differences are apparent upon inspection of the diagrams. Clearly, serious differences would result if the rose diagram derived from the lineament map were to be substituted for that obtained from the geologic maps during any sort of structural analysis and the one cannot be regarded as a statistically valid substitute for the other. Efforts are now underway to determine the reasons for this

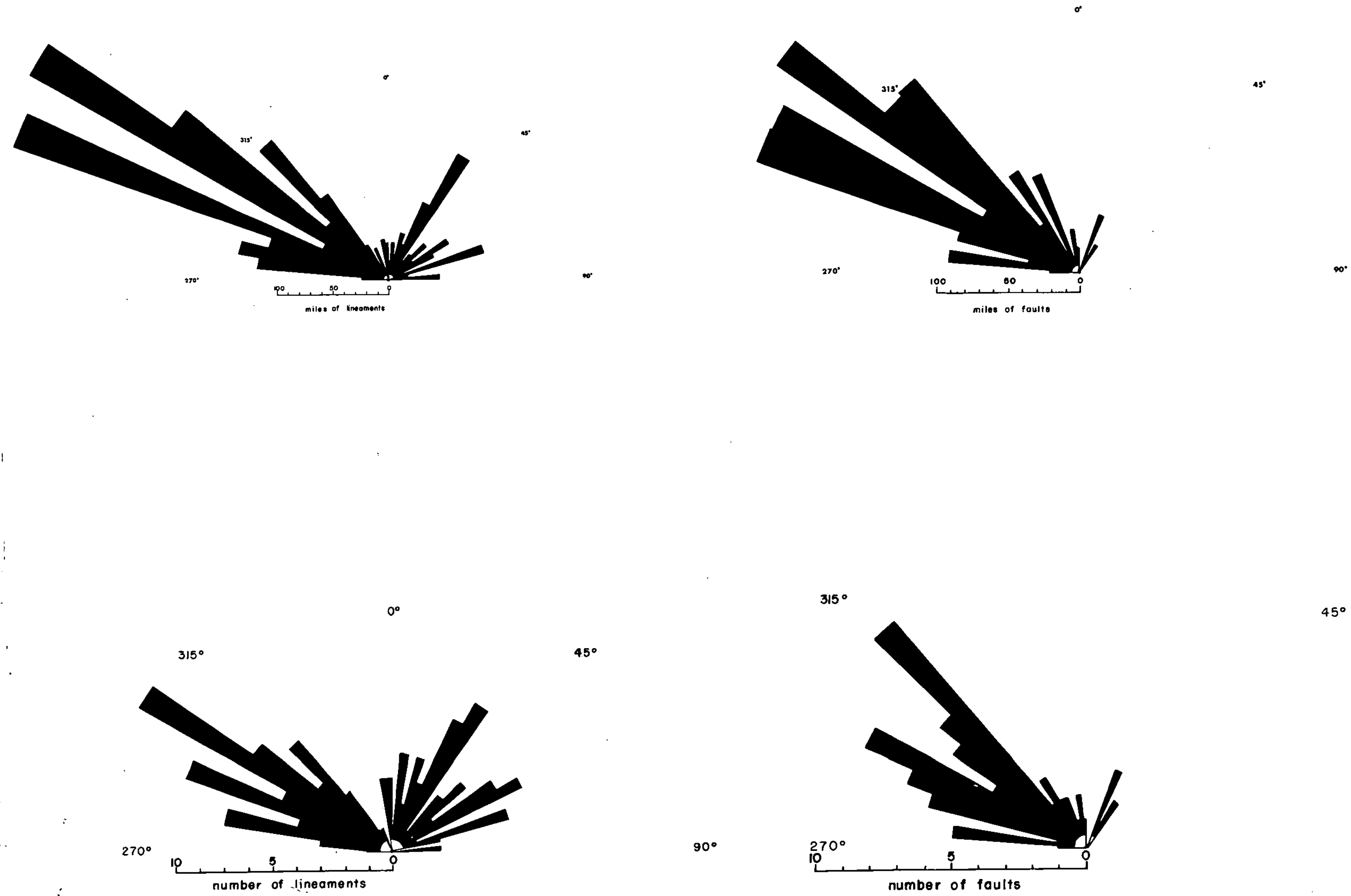

Figure 7. Rose diagrams for western Lewis and Clark lineaments structural domain (Domain 1 of Figure 6). ERTS lineaments on left; mapped faults on right (from Kleinkopf and others, 1972).

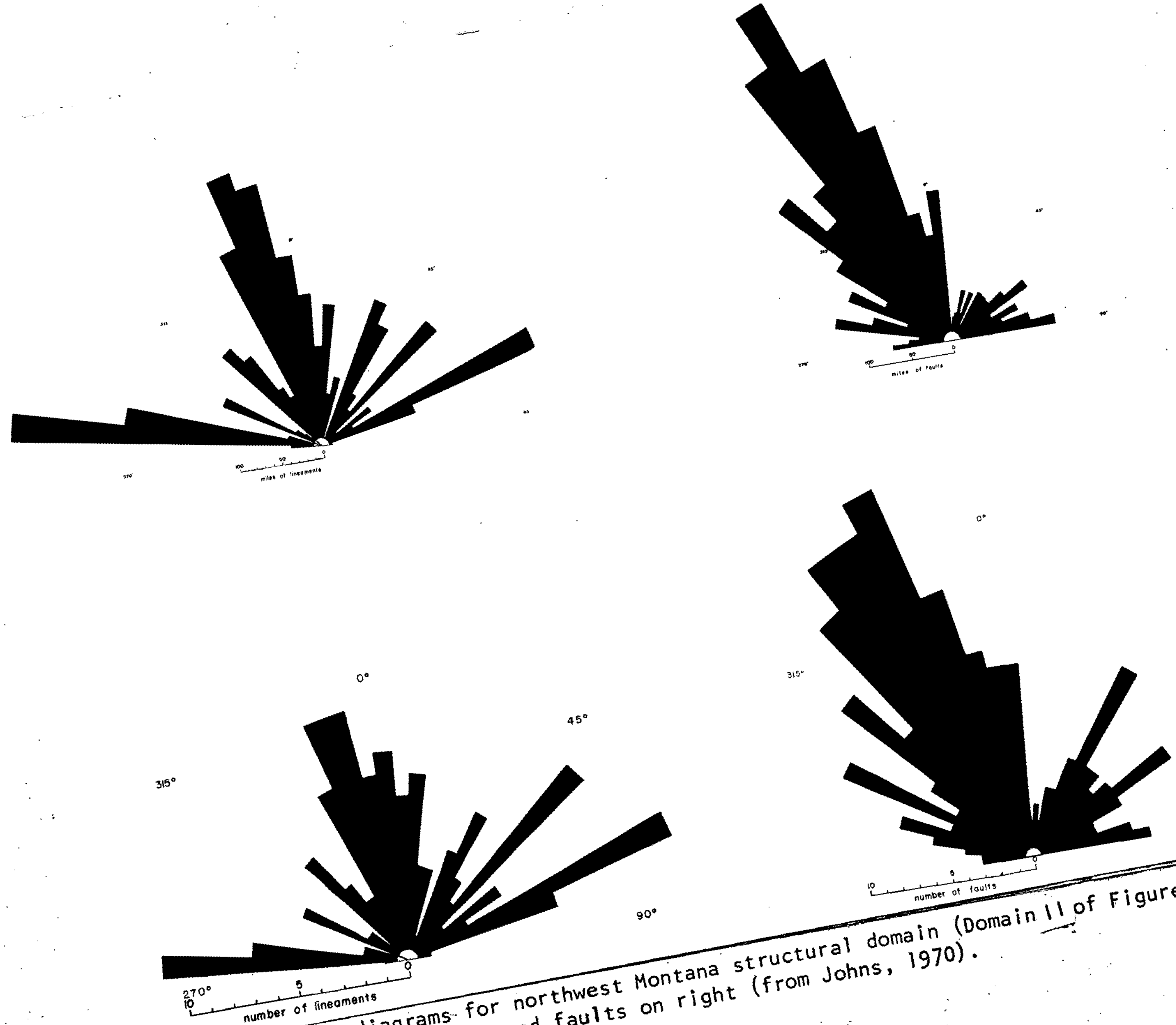

Figure 8. Rose diagrams for northwest Montana structural domain (Domain II of Figure 6). ERTS lineaments on left; mapped faults on right (from Johns, 1970).

difference and establish whether the lineament map or the geologic maps are more nearly valid for structural analysis.

Our preliminary conclusions from this work, still tentative, are that ERTS-1 imagery will be useful in obtaining statistically valid and useable lineament patterns of strongly deformed regions even in the presence of heavy soil and forest cover. However, their usefulness as a short cut to geologic mapping in such regions will probably be limited. In heavily forested regions that are not strongly deformed, there appears to be considerable risk that lineament patterns obtained from ERTS imagery may be seriously misleading. Application of ERTS photographs to geologic investigation of arid or semi-arid regions appears likely to be much more straightforward.

Willis Johns of the Montana Bureau of Mines and Geology has submitted a lineament map in a progress report covering his investigation of Test Site 354 B. This work was done independently of the detailed regional annotations of Figure 6, and is based on ERTS imagery for both Bands 5 and 7. Included are east-west lines in the Big Fork area not previously mapped as faults. This map will be evaluated by annotating a U-2 mosaic and by field work, after which it will be modified to indicate the geologic meaning of each line. The completed map should aid in understanding why the statistical summary of lineaments in the area differs from that for existing geologic maps (Figure 8).

Several unexpected lineament patterns emerged during annotation of the ERTS imagery (Figure 6). The most striking of these is an unmistakably prominent set of nearly north-trending lineaments within the Idaho batholith. These extend directly northward from the Snake River volcanic plain of southern Idaho and it seems likely that they may be the result of east-west crustal extension. Efforts will be made to ascertain the nature of this lineament set and establish a date for its formation.

Another unexpected lineament pattern was noted in the Boulder batholith of western Montana where an almost polygonal pattern of long, arcuate lineaments intersected by short transverse lineaments is apparent on the ERTS imagery. As far as the present investigators are aware, this pattern had not been observed prior to study of ERTS imagery. Two undergraduate students working under the auspices of an NSF Undergraduate Research Participation

Program have attempted to determine the nature and implications of this pattern. They have carefully annotated the lineament pattern and transferred it to large-scale topographic maps on which they also plotted locations of all mining activity, past and present, in the Boulder batholith and its immediate environs. No significant correspondence was noted so it must be concluded that ERTS lineaments are not a straightforward guide to mineralization in the Boulder batholith. The same two students are continuing the work with a view toward determining, if possible, the bedrock explanation of the lineament pattern visible in the imagery.

Several large radial dike swarms exist within the region in the areas of the Crazy, Highwood and Adel mountains. None of the dikes in the Highwood Mountains were visible in the imagery and very few of those in the Crazy and Adel mountains could be recognized. Those noted were insufficient to reveal the existence of radial dike swarms.

Numerous circular features were noted during annotation of the imagery for the lineament map. These are not shown on the map but efforts are underway to determine the nature of those which lack obvious geologic explanations. Most of the ones already checked have turned out to be previously mapped igneous intrusions, stocks or laccoliths. No suspected impact structures have yet been found.

Future work with the lineament map will involve continued efforts at evaluation to determine more precisely the extent to which it corresponds to geology that might be obtained through conventional ground mapping procedures. This will require continued statistical evaluation combined with local field checking and consultation with geologists experienced in various areas. Efforts will also be made to find ways of using data contained in the map to interpret the geology and ways of recognizing more types of structures.

Photogeologic Mapping Investigations

Test Site 354 A&C, B

A cooperative, non-funded photogeologic mapping study of Quaternary deposits in the Glacial Lake Missoula basin is being conducted by W. Mark Weber (Minot State College, North Dakota), who is familiar with the mapping units from a previous detailed ground study (Weber, 1972). A photogeologic map has been compiled for parts of Test Sites 354 A&C and B by overlay annotation using U-2 metric camera color infrared transparencies under the zoom stereoscope (NASA-ERAP Flight 72-125). This work has demonstrated the feasibility of differentiating and mapping deposits of glacial, glacio-lacustrine, lacustrine-outburst flood, and alluvial origins. Ground truth checks together with an examination of previously published maps have confirmed the photogeologic interpretations. In parts of the area, previously unrecognized deposits and stratigraphic relationships have been delineated by photogeologic interpretation. Examination of ERTS black and white imagery and displays on the color additive viewer is currently in a preliminary phase, and no conclusions as to the feasibility of differentiating between various surficial deposits using the space imagery is warrented at this time.

Test Site 354 D

Consultant Charles J. Vitaliano of Indiana University spent eight days in Missoula studying ERTS imagery and U-2 photography of Test Site 354 D, which includes the Tobacco Root and southern Elkhorn Mountains, a semi-arid area for which he has extensive first-hand knowledge of geologic ground truth. Dr. Vitaliano prepared photogeologic maps based on late summer and fall ERTS Band 7 imagery at scales of 1:500,000 and 1:250,000. These maps, which are available at this time only in non-reproducible form (color on acetate overlays), will be developed into training keys for geologists unfamiliar with the ground truth of the area so that they may draw ERTS photogeologic maps for comparison and evaluation. Professor Vitaliano has submitted a lengthy report, which is briefly summarized below.

Linear features of all kinds, including faults, joint sets, sedimentary contacts in deformed sections, and dikes are readily discernible and can be annotated on either ERTS-1 of U-2 materials to give a very satisfactory representation of geologic ground truth. Identification of rock types is much more difficult and the results much less satisfactory. Irregular boundaries between major rock units can be discerned to a limited extent on ERTS-1 imagery by an investigator who possesses some background of ground truth knowledge of the area.

Criteria for recognition of major rock units in ERTS Band 7 imagery involve a combination of tonal shading, patterns of linear elements, structural habit, and land use practices. Precambrian crystalline basement rocks are characterized by an intermediate tone and subtle indication of very close folding and structural grain. Precambrian sedimentary rocks, "Belt Supergroup", are also intermediate in tone and show subtle evidence of stratification in the form of long parallel lineaments. Their habit of occurring in the cores of major anticlines is also helpful. Paleozoic and Mesozoic sedimentary rocks generally show strong evidence of stratification and a landscape of ridges and valleys developed along the strike of beds.

Large granitic intrusives are generally intermediate in tone, but are lighter than the Precambrian crystalline basement rocks and Belt strata; they show prominent intersecting sets of fractures. The intermediate volcanic rocks genetically related to the Boulder batholith (Elkhorn Mountains Volcanics) are rather dark in tone; they show faint evidence of layering and generally only one subdued set of fractures. Tertiary basin fill deposits are generally lighter in tone than adjacent bedrock and show strong cultivation patterns. They reveal little evidence of bedding because they are generally only slightly deformed and not deeply eroded. All these criteria appear to hold only where vegetative cover is sparse and fail in heavily forested localities such as the higher slopes of the Tobacco Root Mountains.

Professor Vitaliano concludes, "ERTS imagery provides an excellent means for annotation of lineaments of many types and recognition of strikingly different geologic units . . . ERTS imagery will be a powerful tool for geologic mapping in the future." He qualifies this conclusion by noting, "It appears that some knowledge of ground truth is required in order to distinguish at least some geologic units. More particularly, some knowledge of ground truth is necessary in order to delineate geologic contacts with some degree of certainty, and ideal conditions are obtained when there is knowledge of approximately 25 percent of the geology in any given area . . . It is felt that under similar conditions consistently good results would be obtainable in other test site areas, especially in Montana and neighboring states."

Test Site 354 F

Preliminary photogeologic maps for the test site located in the Roundup area of eastern Montana were drawn without reference to known geology using overlays on ERTS Band 7 imagery. This effort resulted in discontinuous form lines which clearly reveal several known folds but do not show the broad, forest-covered Bull Mountain syncline. Lineament annotation shows 15 en echelon elements of the Lake Basin fault zone north and west of Billings. Fall imagery (ID # 1122- 17350 and 17353) was much better for interpretation than late August and September imagery; 1:500,000 scale prints yielded more data than 1:1,000,000 scale prints. Experimentation with 1:250,000 scale prints allowed better delineation of detail, but did not show geology which could not be seen on the 1:500,000 scale prints.

Annotations were also made on overlays on U-2 metric camera color infrared transparencies studied stereoscopically. As anticipated, this work was more precise and yielded more detail than the black and white ERTS imagery. The overlays were reduced to a scale of 1:500,000 and compared to the state geologic map which proved to be obviously generalized and lacking in detail.

Clearly, ERTS annotations based on calibration of photogeologic units from key areas of ground geologic map control supplemented by high altitude photography will be useful as a tool for photogeologic mapping in eastern Montana. To test this approach, ERTS imagery of the test site will be re-annotated by operators unfamiliar with its geology using photolithologic recognition criteria developed for key areas.

Southeast Montana

An independent student investigation for the area south and east of the confluence of the Missouri and Musselshell Rivers using 1:1,000,000 scale Band 5 and 7 prints demonstrates that as many as eight photogeologic units may be recognized and mapped within a single scene (ID # 1085-17291). The investigation suggests an area of Wasatch Formation on the divide between Rosebud Creek and the Tongue River which is not shown on the Geologic Map of Montana. Attempts to carry the map units into images of other orbits indicate change in tonal or textural character which may be related to facies change. This work will be expanded and evaluated by field checking.

PROGRAM FOR NEXT REPORTING INTERVAL

During the next two months, intensive efforts will be made to determine the nature of ERTS lineaments and evaluate the significance of the detailed ERTS lineament map. ERTS lineaments that clearly coincide with structures shown on published geologic maps will be largely excluded from further consideration. New lineaments will be identified and investigated further, first on U-2 photographs, where those are available, and finally on the ground in cases where such inspection seems likely to be useful.

Statistical comparison of the pattern of ERTS lineaments with that of published geologic maps will continue for selected areas to reveal any systematic deviations of whole sets of features, as opposed to isolated instances. One such deviation has already appeared, in northwestern Montana, and efforts are now underway to establish an explanation. These will involve further detailed comparison of the ERTS imagery with the maps, a conference with Willis Johns who is a participant in the project and the geologist most familiar with the region, and field checking of selected lineaments by Johns and others.

Attention will be directed to the strong lineament pattern in the Idaho batholith which appears to represent major geologic structures previously unreported. All available literature on the Idaho batholith, of which there is remarkably little, represents it as being internally undeformed. Nevertheless, the batholith must have participated in the large tectonic movements that have involved the Rocky Mountain region during Cenozoic time. It seems likely that interpretation of the lineaments within the batholith may be an important contribution to understanding of the structural development of the region.

William J. McMannis, a consultant to the project, will prepare annotations of ERTS imagery to evaluate the relationship of structural patterns within the Crazy Mountains basin of south central Montana to structural patterns in the peripheral uplifts. This work will cover an area of interest to petroleum geologists.

Work has also begun on detailed annotation of U-2 photography and ERTS imagery in Test Sites 354 A&C. This will lead to evaluation of a number of ERTS lineaments along the trend of the Lewis and Clark lineaments and may also contribute to interpretation of these structures, a suspected continental transform fault. Linda Wackwitz, a graduate student in geology and research assistant to the project, will be basing her master's thesis on this work.

Determined attempts made last winter to establish criteria for recognition of rock types in ERTS imagery met with limited success. With year-long imagery now available, we will attempt seasonal comparisons for selected areas and rock types. Renewed efforts will be made and will be centered around Test Site 354 D for which Charles J. Vitaliano, a consultant to the project, has suggested recognition criteria based on late summer and fall imagery.

Throughout all phases of the work, part of the investigators' attention will be directed to the problem of geologic interpretation of the ERTS imagery. The status of geologic mapping and interpretation in the northern Rocky Mountains is generally rather laggard for a variety of good reasons. Every geologist familiar with the region who has examined the ERTS imagery received at the University of Montana has agreed that it should be most helpful in improving knowledge of regional geology and leading to syntheses and interpretation on a large scale. When this potential begins to be realized, the ERTS imagery will begin to bring major benefit.

CONCLUSIONS

There is no doubt that lineament annotation of ERTS imagery reveals patterns of high-angle faulting that are substantially similar to those obtained from painstaking mapping on the ground, providing a rapid and very economical method to prepare a tectonically meaningful map of unmapped regions and to refine the tectonic picture for incompletely mapped areas, even where forest cover is dense. It seems likely that lineament annotation will lead to large-scale tectonic interpretations much more rapidly than conventional geologic methods. Even in places where annotation did not precisely locate major faults, the general structural trend and style were reliably revealed. Study of ERTS imagery should certainly become the first step in investigating the geology of any area.

Recognition and mapping of rock units from ERTS imagery alone continues to be an elusive goal, particularly for heavily forested terrain in western Montana. However, studies during the reporting period have been encouraging with respect to Mesozoic and Tertiary units in eastern Montana. The mapping of various Quaternary deposits in the Glacial Lake Missoula basin of western Montana on U-2 color infrared photography suggests the possibility of similar ERTS image mapping using color composite imagery. Our experience suggests that the most fruitful approach to photolithologic recognition and mapping should involve working out recognition keys from ground truth up, utilizing U-2 photography and taking into account seasonal influences.

ERTS imagery promises to be a vehicle for rapid, inexpensive tectonic mapping and an aid in preparation of small scale geologic maps.

RECOMMENDATIONS

We recommend Fall 1973 recoverage by U-2 aircraft for parts of our western Montana test sites. This recommendation is based on two limitations of the 26 July 1972 photo coverage. One is obscuration by clouds (50-100 percent cover for a number of frames). The other is the lack of usable infrared-band Vinten camera photographs due to extreme underexposure of existing coverage. Recoverage would overcome these limitations and provide photographic bridge to Fall ERTS imagery, as well as an improved basis for evaluating seasonal influence on spectral signatures of gross rock units. Ideally, coverage should be made after leaf fall and before snowfall.

If possible, additional coverage of a portion of the eastern part of the Idaho batholith should be added. The strong pattern of north-trending lineaments observed there in ERTS imagery probably represent previously unknown major structures that may be significant to an understanding of the geology of the Rocky Mountains. Investigation of those lineaments is difficult because they are in remote terrain consisting entirely of granitic rocks.

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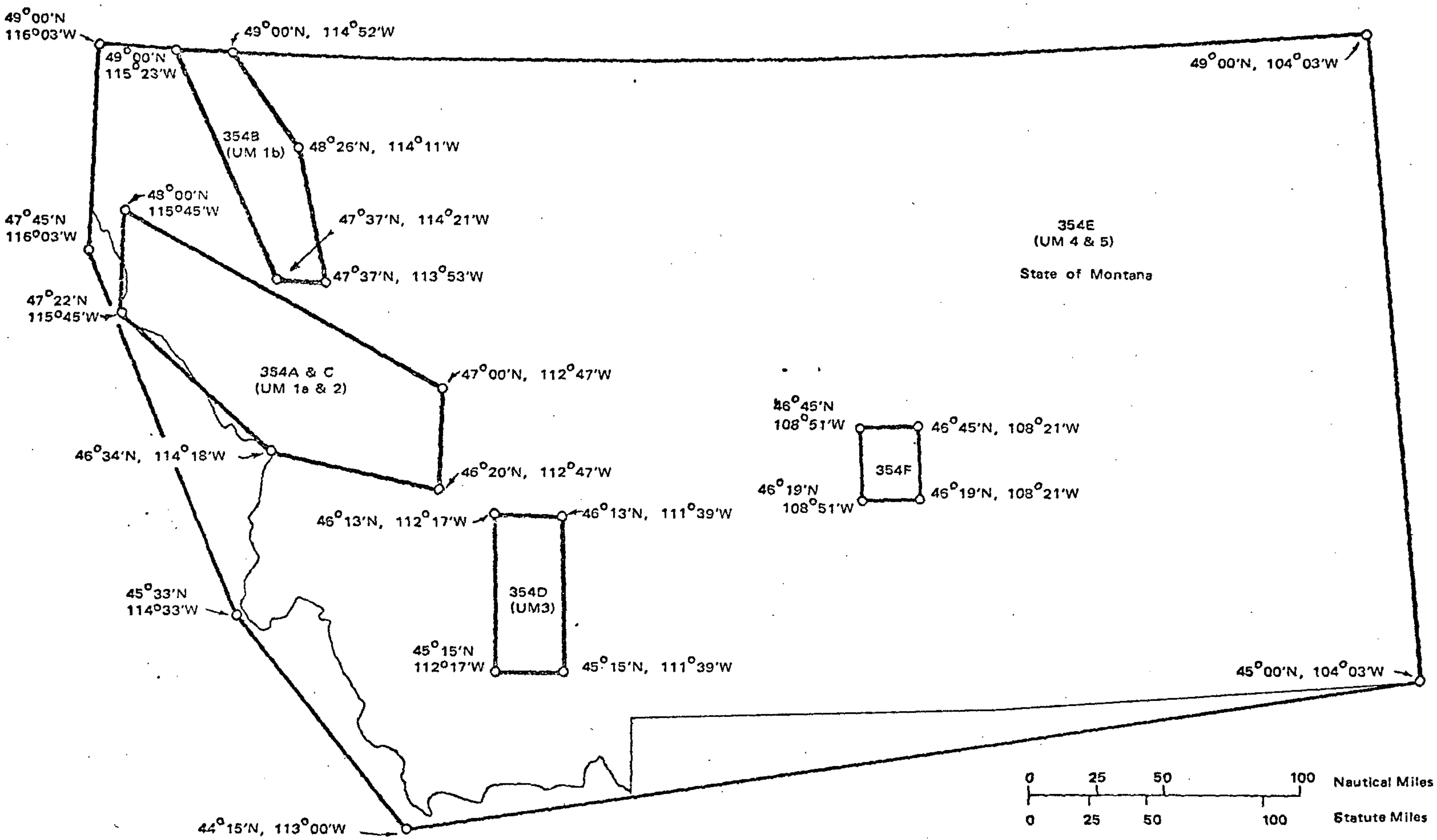

University of Montana ERTS-A Test Sites. Identification is by NASA site numbers (354A) and University of Montana proposal numbers (UM 1a).